

**APPLICATION
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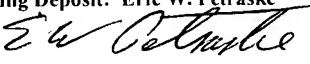
For:

“Oxide/Nitride Stacked FinFET Spacer Process”

Docket: YOR920030417US1

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Oxide/Nitride Stacked FinFET Spacer Process

TECHNICAL FIELD

The field of the invention is that of fabricating field effect transistors having a body extending perpendicular to the semiconductor substrate between horizontally disposed source and drain regions, referred to as a "FinFET".

BACKGROUND OF THE INVENTION

Metal-Oxide-Semiconductor field effect transistor (MOSFET) technology is the dominant electronic device technology in use today. Performance enhancement between generations of devices is generally achieved by reducing the size of the device, resulting in an enhancement in device speed. This is generally referred to as device "scaling".

Ultra-large-scale integrated (ULSI) circuits generally include a multitude of transistors, such as more than one million transistors and even several million transistors that cooperate to perform various functions for an electronic component. The transistors are generally complementary metal oxide semiconductor field effect transistors (CMOSFETs) which include a

1 gate conductor disposed between a source region and a drain region. The
2 gate conductor is provided over a thin gate oxide material. Generally, the
3 gate conductor can be a metal, a polysilicon, or polysilicon/germanium (Si_x
4 $\text{Ge}_{(1-x)}$) material that controls charge carriers in a channel region between the
5 drain and the source to turn the transistor on and off. The transistors can be
6 N-channel MOSFETs or P-channel MOSFETs.

7 In bulk semiconductor-type devices, transistors such as MOSFETs, are built
8 on the top surface of a bulk substrate. The substrate is doped to form source
9 and drain regions, and a conductive layer is provided between the source
10 and drain regions. The conductive layer operates as a gate for the transistor;
11 the gate controls current in a channel between the source and the drain
12 regions. As transistors become smaller, the body thickness of the transistor
13 (or thickness of depletion layer below the inversion channel) must be scaled
14 down to achieve superior short-channel performance.

15 As MOSFETs are scaled to channel lengths below 100 nm, conventional
16 MOSFETs suffer from several problems. In particular, interactions between
17 the source and drain of the MOSFET degrade the ability of the gate to
18 control whether the device is on or off. This phenomenon is called the
19 "short-channel effect".

20 Silicon-on-insulator (SOI) MOSFETs are formed with an insulator (usually,
21 but not limited to, silicon dioxide) below the device active region, unlike
22 conventional "bulk" MOSFETs, which are formed directly on silicon

1 substrates, and hence have silicon below the active region.

2 Conventional SOI-type devices include an insulative substrate attached to a
3 thin-film semiconductor substrate that contains transistors similar to the
4 MOSFETs described with respect to bulk semiconductor-type devices. The
5 insulative substrate generally includes a buried insulative layer above a
6 lower semiconductor base layer. The transistors on the insulative substrate
7 have superior performance characteristics due to the thin-film nature of the
8 semiconductor substrate and the insulative properties of the buried
9 insulative layer. In a fully depleted (FD) MOSFET, the body thickness is so
10 small that the depletion region has a limited vertical extension, thereby
11 eliminating link effect and lowering hot carrier degradation. The superior
12 performance of SOI devices is manifested in superior short-channel
13 performance (i.e., resistance to process variations in small size transistors),
14 near-ideal subthreshold voltage swing (i.e., good for low off-state current
15 leakage), and high saturation current. SOI is advantageous since it reduces
16 unwanted coupling between the source and the drain of the MOSFET
17 through the region below the channel. This is often achieved by ensuring
18 that all the silicon in the MOSFET channel region can be either inverted or
19 depleted by the gate (called a fully depleted SOI MOSFET). As device size
20 is scaled, however, this becomes increasingly difficult, since the distance
21 between the source and drain is reduced, and hence, they increasingly
22 interact with the channel, reducing gate control and increasing short channel
23 effects (SCE).

1 The double-gate MOSFET structure is promising since it places a second
2 gate in the device, such that there is a gate on either side of the channel.
3 This allows gate control of the channel from both sides, reducing SCE.
4 Additionally, when the device is turned on using both gates, two conduction
5 ("inversion") layers are formed, allowing for more current flow. An
6 extension of the double-gate concept is the "surround-gate" or "wraparound-
7 gate" concept, where the gate is placed such that it completely or almost-
8 completely surrounds the channel, providing better gate control.

9 In a double gate field effect transistor (FinFET), the device channel
10 comprises a thin silicon fin standing on an insulative layer (e.g. silicon
11 oxide) with the gate in contact with the sides of the fin. Thus inversion
12 layers are formed on the sides of the channel with the channel film being
13 sufficiently thin such that the two gates control the entire channel film and
14 limit modulation of channel conductivity by the source and drain.

15 The double gates on the channel fin effectively suppress SCE and enhance
16 drive current. Further, since the fin is thin, doping of the fin is not required
17 to suppress SCE and undoped silicon can be used as the device channel,
18 thereby reducing mobility degradation due to impurity scattering. Further,
19 the threshold voltage of the device may be controlled by adjusting the work
20 function of the gate by using a silicon-germanium alloy or a refractory metal
21 or its compound such as titanium nitride.

22 Generally, it is desirable to manufacture smaller transistors to increase the

1 component density on an integrated circuit. It is also desirable to reduce the
2 size of integrated circuit structures, such as vias, conductive lines,
3 capacitors, resistors, isolation structures, contacts, interconnects, etc. For
4 example, manufacturing a transistor having a reduced gate length (a reduced
5 width of the gate conductor) can have significant benefits. Gate conductors
6 with reduced widths can be formed more closely together, thereby
7 increasing the transistor density on the IC. Further, gate conductors with
8 reduced widths allow smaller transistors to be designed, thereby increasing
9 speed and reducing power requirements for the transistors.

10 Heretofore, lithographic tools are utilized to form transistors and other
11 structures on the integrated circuit. For example, lithographic tools can be
12 utilized to define gate conductors, active lines conductive lines, vias, doped
13 regions, and other structures associated with an integrated circuit. Most
14 conventional lithographic fabrication processes have only been able to
15 define structures or regions having a dimension of 100 nm or greater.

16 In one type of conventional lithographic fabrication process, a photoresist
17 mask is coated over a substrate or a layer above the substrate. The
18 photoresist mask is lithographically patterned by providing electromagnetic
19 radiation, such as ultraviolet light, through an overlay mask. The portions of
20 the photoresist mask exposed to the electromagnetic radiation react (e.g. are
21 cured). The uncured portions of the photoresist mask are removed, thereby
22 transposing the pattern associated with the overlay to the photoresist mask.
23 The patterned photoresist mask is utilized to etch other mask layers or

1 structures. The etched mask layer and structures, in turn, can be used to
2 define doping regions, other structures, vias, lines, etc.

3 As the dimensions of structures or features on the integrated circuit reach
4 levels below 100 nm or 50 nm, lithographic techniques are unable to
5 precisely and accurately define the feature. For example, as described
6 above, reduction of the width of the gate conductor (the gate length)
7 associated with a transistor or of the active lines associated with an SOI
8 transistor has significant beneficial effects. Future designs of transistors
9 may require that the active lines have a width of less than 50 nanometers.

10 Double gate SOI MOSFETs have received significant attention because of
11 its advantages related to high drive current and high immunity to short
12 channel effects. The double-gate MOSFET is able to increase the drive
13 current because the gate surrounds the active region by more than one layer
14 (e.g., the effective gate total width is increased due to the double gate
15 structure). However, patterning narrow, dense active regions is challenging.
16 As discussed above with respect to gate conductors, conventional
17 lithographic tools are unable to accurately and precisely define active
18 regions as structures or features with dimensions below 100 nm or 50 nm.

19 Thus, there is a need for an integrated circuit or electronic device that
20 includes smaller, more densely disposed active regions or active lines.
21 Further still, there is a need for a ULSI circuit which does not utilize
22 conventional lithographic techniques to define active regions or active lines.

1 Even further still, there is a need for a non-lithographic approach for
2 defining active regions or active lines having at least one topographic
3 dimension less than 100 nanometers and less than 50 nanometers (e.g., 20-
4 50 nm). Yet further still, there is a need for an SOI integrated circuit with
5 transistors having multiple sided gate conductors associated with active
6 lines having a width of about 20 to 50 nm.

7 The present invention is directed to a process for fabricating FinFET
8 transistor structures which is an extension of conventional planar MOSFET
9 technology and resulting structures.

10 SUMMARY OF THE INVENTION

11 The present invention is directed to a process for fabricating FinFET
12 transistor structures, in which the fins in the Source/Drain (S/D) area are
13 increased in thickness by epitaxial silicon growth while the transistor bodies
14 under the gates remain at the design value.

15 A feature of the invention is the use of a gate spacer process that enables the
16 formation of an encapsulated gate while the sidewall of the fins is cleared
17 and thickened.

1 A feature of the invention is that a conformal layer of a material resistant to
2 an oxide etch is formed on the gates to protect the gates while the S/D area
3 of the fins is cleaned of oxide.

4 Another feature of the invention is the anisotropic etch of a layer of oxide
5 on the lower portion of the gates, leaving an oxide spacer that is not
6 removed during the removal of oxide on the fins.

7 BRIEF DESCRIPTION OF THE DRAWINGS

8 Figure 1 shows in cross section a preliminary step in the process of forming
9 the invention, showing fins formed before the gate formation.

10 Figure 2A shows the fins in the S/D area; Figure 2B shows a cross section
11 through the gate; and Figure 2C shows a cross section through the gate
12 looking perpendicular to the fin. Figure 2D is a top view showing the
13 location of the other Figures.

14 Figure 3A shows the S/D area after an optional step to add a liner on the
15 fins and the deposition of an oxide filler.

16 Figure 3B shows the same area as Figure 2B.

17 Figure 3C shows the oxide planarized to the level of the gate cap.

1 Figures 4A and 4C show the corresponding area to Figure 3A and 3C after
2 recess of the oxide. Figure 4B is unchanged.

3 Figure 5A - 5C show the previous figures after the deposition of a
4 conformal liner.

5 Figure 6A - 6C show the result of converting the conformal liner to gate
6 spacers.

7 Figure 7A - 7C show a second oxide fill and planarization.

8 Figure 8A - 8C show the result of etching the oxide to expose the fins in the
9 S/D area and encapsulate the gate.

10 Figures 9A, 9B and 9C show cross sections at the end and middle of the fins
11 after stripping the nitride.

12 Figures 10A and 10B show cross sections at the end and middle of the fins
13 after epitaxial deposition of additional silicon on the fins in the S/D area.

14 DETAILED DESCRIPTION

15
16 This invention describes a process to fabricate FinFET transistors using a
17 gate spacer process that enables the formation of an encapsulated gate while

1 the sidewall of the fins is cleared. Clearing the fin sidewall from unwanted
2 spacer material but still keeping a cap on top and spacer material on the side
3 of the gate is quite difficult as a long overetch of the gate spacer is required.
4 This overetch that clears the sidewall of the fins also consumes the cap on
5 top of the gate and the spacer on the side of the gate, increasing the
6 possibility of exposing polysilicon from the gate. Cleared fin sidewalls are
7 necessary to increase the fin thickness outside of the gate to reduce series
8 resistance. If polysilicon from the gate is exposed, epitaxial growth will also
9 occur on the gate. The uncontrolled epitaxial growth on the gate can cause
10 shorting of gate and source/drain during silicidation. It also can result in
11 unwanted shadowing of later ion implants.

12 Referring now to Figure 1, there is shown in cross section a portion of an
13 integrated circuit that will contain a set of FinFET transistors. Wafer 10
14 may be bulk silicon or an SOI wafer. The SOI wafer is preferred and is
15 illustrated here. Above substrate 10, buried oxide insulator (BOX) layer 20
16 has been formed by conventional processes. Sitting on top of BOX 20 are
17 blocks of silicon 30 (capped with oxide 32) extending perpendicular to the
18 plane of the paper that will form the fins of FinFETs. The plane of the cross
19 section in Figure 1A is taken through the S/D area and in Figure 1B through
20 the location where transistor gates will be placed in later steps. Figure 1C is
21 a top view showing the location of cross sections 1A and 1B. Rectangles 32
22 are the top views of the fins in Figures 1A and 1B. Only two of the four fins
23 30 are shown for economy. The horizontal dimensions appearing in the
24 cross section will be referred to as transverse dimensions. For convenience

1 in explanation, the top of Figure 1C will be referred to as North, with other
2 directions corresponding. Thus, Figure 1A is a cross section taken at the
3 North end of the fins, looking north.

4 Blanket implants may be done at any convenient time.

5 Illustrative ranges for the SOI silicon layer thickness that is formed into
6 blocks 30 are 1000Å to 2000Å. A thermal oxide 32 is grown to a thickness
7 of 300Å (ranging between 30Å-1000Å) on the surface of the silicon using
8 thermal diffusion processes. Alternatively the oxide can be deposited with
9 the same thickness using CVD processes.

10 In this example, a set of four fins shown will be controlled by a common
11 gate. Those skilled in the art will be aware that separated gates could be
12 formed to control one or more fins, if desired. As used herein, the term
13 “set” means one or more; i.e. a FinFET may have one or more fins. The
14 Figure shows the result of conventional preliminary steps, well known to
15 those skilled in the art, of forming the silicon fins for a FinFET.

16 Narrow fin structures in silicon or silicon on insulator (SOI) can be
17 fabricated in different ways, e.g. by optical lithography followed by
18 different trimming techniques (resist trimming, hard mask trimming,
19 oxidation trimming (These processes are based on width reduction of the
20 mask by plasma etch or wet etch, or by material consumption of the fin by
21 oxidation)), by E-beam lithography or by sidewall image transfer processes.

1 In the example illustrated, the sidewall image transfer process was used as
2 the method to structure narrow fins in SOI. Figure 1 shows a bulk wafer 10,
3 having a buried oxide (BOX) 20 with an SOI layer 30 of 70nm (Possible
4 range of the SOI is ~10nm to 200nm, but not limited to that range). The
5 surface of layer 30 has been oxidized to form 300Å of thermal oxide 32
6 (Preferred range 50Å-500Å). Alternatively, an oxide can also be deposited
7 using any kind of CVD processes.

8 The following discussion illustrates a conventional method, well known to
9 those skilled in the art, of fabricating the structure shown in Figure 1. Other
10 methods may also be used. These initial steps are not illustrated in the
11 Figures to avoid unnecessary detail. Initially, 1500Å (Preferred range 500Å
12 -3000Å) of temporary amorphous silicon (not shown) were deposited on the
13 wafer surface that will be formed into the fins (oxide layer 32 on top of fin
14 layer 30) by CVD or sputter processes, followed by the deposition of 500Å
15 (Preferred range 100Å -2000Å) of CVD oxide (not shown) as a hardmask.
16 Optical lithography and RIE etch processes are used to structure the CVD
17 oxide hardmask and, using the CVD oxide hardmask, the amorphous silicon
18 layer, stopping on the oxide layer 32 on top of the SOI to form a temporary
19 structure that supports the conformal layer that follows. Then a 200Å
20 (Preferred range 50Å - 500Å) nitride layer (not shown) is deposited
21 conformally using a CVD process followed by a RIE etch process to form
22 SiN spacers (sidewalls) on the side of the amorphous silicon.

1 The amorphous silicon is then removed with a plasma etch or wet etch
2 leaving nitride spacer structures behind. The spacer structures are used as a
3 hardmask to structure the oxide 32 underneath and can be removed
4 afterwards by oxide and silicon selective plasma etches or wet etches (e.g.
5 hot phosphoric acid). The structured oxide 32 is then used as a hardmask to
6 etch the silicon fins 30 in the SOI layer, resulting in the example shown in
7 Figure 1. Next, a sacrificial oxide is thermally grown to remove RIE damage
8 from the silicon fin surface and to act as a screen oxide for fin body doping
9 implants that can be processed at this point. Fin body doping implants are
10 not necessary to make the FinFET device work, but can be useful to set
11 FinFET V_t .

12 The sacrificial oxide is removed by a wet etch, followed by a preclean and
13 gate oxide processing using thermal oxidation or CVD deposition processes.
14 A specific example of the process described above is shown in copending
15 patent application Attorney Docket Number YOR920030433US1, assigned
16 to the assignee hereof and incorporated herein by reference and omitted
17 from this description for simplicity.

18 Referring now to Figures 2B and 2C, a polysilicon layer 40 of 1300Å
19 (Preferred range 300Å - 3000Å, depending on total fin height) is deposited
20 using a CVD process and then planarized by a CMP or planarizing
21 coating/etchback processes to improve the process window of the gate
22 lithography step later in the process. Optional poly pre-doping to adjust the
23 gate work function for NFETs and PFETs is followed by a low temperature

1 CVD deposition of 400Å nitride 45 that forms a protective cap.

2 As explained below, the total height of a hardmask formed by layer 45
3 needs to be greater than silicon fin 30 height plus the oxide 32 on fin plus a
4 process margin. Before the nitride deposition, an optional oxide layer 42
5 (Preferred range 20Å-500Å) can be deposited to act as stress buffer between
6 the nitride and the polysilicon. For convenience in the illustration, layer 42
7 is shown as a single line. On top of the nitride 45 another hardmask layer
8 46 is deposited, e.g. CVD oxide, with a thickness of 1000Å (Preferred
9 Range 100Å - 2000Å. The complete hardmask stack (e.g. oxide on nitride
10 on oxide on polysilicon) is patterned lithographically to remove oxide 46
11 outside rectangle 45 in Figure 2D. Oxide 46 within rectangle 45 then serves
12 as a hardmask during the etching of nitride 45, oxide 42 and poly 40. Oxide
13 layer 46 is shown in Figs 2B and 2C after the nitride and polysilicon etch,
14 so that most of it has been consumed.

15 Figure 2D is the same as Figure 1C with the addition of rectangle 45, which
16 represents the vertical pillar in Figure 2C. Rectangle 45 defines the gate for
17 the FinFET. The sources and drains are the portions of the fins (vertical
18 rectangles) in Figure 2D outside rectangle 45. In Figure 3 and the following
19 figures, Figures n-A, n-B and n-C will have the same orientation as Figures
20 2A, 2B and 2C, respectively.

21 The Nitride 45 has been structured as described above using optical
22 lithography (the area shown as box 45 in Figure 2D), e-beam lithography or

1 sidewall image transfer processes, and RIE to form a hardmask. Using the
2 hardmask, a poly etch forms structure 40 extending E-W that will become
3 the selfaligned gate. The result of the lithographic step forming the poly
4 gate is that Figure 2A shows the same view as Figure 1A in the S/D region,
5 while Figure 2B shows the poly structure capped by a nitride hardmask.
6 Figure 2C shows a view looking E along the poly structure.

7 The fin 30 extends horizontally in Figure 2C and the gate 40 extends
8 perpendicular to the plane of the paper, with the plane of the cross section
9 within the poly structure and outside the fin. If a gate width having a
10 sub-lithographic dimension is desired, trimming of the nitride hardmask 45
11 on top of the polysilicon can be done by resist trimming techniques or by
12 nitride wet etch or dry etch processes. The nitride hardmask is then used to
13 structure the polysilicon by RIE, forming the gate conductor of the FinFET.
14

15 The length of the transistor body along the fin is set by the width of gate 40
16 along the N-S direction (the left-right distance in Figure 2C). As described
17 below, it is desirable to increase the thickness (the E-W dimension) of the
18 fins 30 in the S/D (Fig. 2A) compared with the corresponding body width in
19 Fig. 2B; i.e. The final width of fins 30 in the S/D region outside rectangle
20 45 will be greater than the width shown in Fig. 2A. The bulk of the steps in
21 this process are directed at protecting the gates 40 during the step of
22 thickening the S/D.

1 The remaining portion of the inventive process involves increasing the
2 thickness of the fins in the S/D area to provide lower resistance. Along with
3 that, a protective sidewall is formed over the gate that prevents the gate
4 form being thickened (which would change the dimension of the transistor
5 body and possibly short the body to the source or drain) and also defining
6 the area of the FinFET that is the transition between the body and the S/D
7 that corresponds to the LDD region in a planar transistor.

8 The next steps in preparation for the S/D thickening are a 30Å gate sidewall
9 oxidation (Preferred range 0Å - 100Å, 0Å meaning, that this step can also be
10 omitted), 30Å CVD oxide liner deposition (Preferred range 0Å - 300Å, 0Å
11 meaning, that this step can also be omitted) and implantations to process
12 halo and extension implants. It should be mentioned that this is not a fixed
13 sequence, e.g. the NFET halo and extension implants can be done after gate
14 sidewall oxidation, the PFET halo and extension implants after the oxide
15 liner deposition. The halo and extension implants are conventional, well
16 known to those skilled in the art. Optionally a CVD nitride liner 37 can be
17 deposited with a thickness of 100Å (Preferred range 30Å - 300Å) as shown
18 in Figure 3A. The nitride liner 37 acts as a protection layer during a later
19 oxide etch to prevent oxide removal of oxide 32 on top of the silicon fin.
20 Nitride liner 37 is optional in that it can be avoided if a selective oxide etch
21 process highly selective to silicon is used, so that fin 30 is not significantly
22 attacked. In this case, the oxide on top of the fin is removed and there will
23 be epitaxial silicon growth.

1 An oxide 50 is deposited and planarized to the level of nitride 45. Figure
2 3C shows layer 50 at the top of nitride 45 and covering the top and sides of
3 the fin 30.

4 Gate nitride cap 45 is the remaining nitride from the nitride hardmask on top
5 of the polysilicon gate 40. The result is shown in Figure 3, with the oxide
6 50 filling the area up to the level of the top of the nitride 45 in Figure 3C.

7 An optional process would do a lithography step at this time to structure the
8 source/drain areas (as shown in Fig. 8) and then continue with the process
9 described below in Figure 4 . In that case, the steps in Figure 7 would not be
10 required. The structural difference of applying the lithography step at this
11 point compared to a later point in the process is that a nitride spacer 65 that
12 is formed later in the process (Fig. 6) would not only be formed at the gate
13 but also around the source/drain area. A disadvantage of this approach is
14 that the nitride spacer, acting as a mask, will leave some free standing oxide
15 fins around the source/drain area after the oxide etch that clears the fin
16 sidewalls. The oxide fins generate some topography, but can be planarized
17 later in the process).

18 The preferred process illustrated here performs the lithography step in
19 Figure 8.

20 The oxide 50 in Fig. 3 is then recessed selective to nitride and silicon to a
21 level above the oxide 32 of the silicon fin using wet or dry etch techniques

1 with gate 40 projecting above the remaining oxide 50 (Figure 4C). By
2 covering the fins in the S/D area, as shown in Fig. 4B and 4A, it is possible
3 to form a material layer 60 (see Fig. 5C) selectively over the gate, to
4 function as a hardmask to define a protective oxide spacer over the gate.

5 As shown in Fig. 5, a conformal layer 60 (Thickness 300Å, Preferred range
6 30Å - 1000Å) is deposited on top of the oxide and the projecting gate
7 structure. The material of the layer is chosen such that the oxide underneath
8 can be anisotropically etched selective to the layer material. Possible
9 material choices are nitride, silicon (amorphous, polycrystalline) or silicon
10 germanium. In the preferred embodiment illustrated, we chose nitride 60 for
11 the layer.

12 In Figure 6C, a nitride spacer 65 is formed by anisotropically etching the
13 nitride layer 60. Figs 6A and 6B remain unchanged, showing that nitride 60
14 is not present in those areas.

15 Figure 7 shows the FinFET structure after CVD oxide 70 deposition and
16 planarization of the oxide down to the nitride cap (45 and 65 in Figs. 7B-C)
17 on top of the gate poly 40 using CMP or any other planarization and etch
18 back technique. The purpose of this oxide deposition is the establishment of
19 a common thickness of oxide to be etched, thus promoting uniformity and
20 increasing the lithographic process window. These steps would be avoided
21 if the lithography step described in the next paragraph and shown in Figure
22 8D is applied earlier (e.g. before Fig. 4).

1 Referring to Fig. 8, a lithography process is then applied to structure the
2 area for source/drain formation by opening an aperture 72 (Fig. 8C) in the
3 enclosing oxide 70 followed by an anisotropic, nitride selective oxide etch
4 stopping on the bottom of the silicon fins to clear the sidewalls of the fins
5 (Fig. 8A). This process will result in some overetch into the BOX 20. If the
6 optional nitride 37 in Figure 3A is deposited, the etch will stop on top of the
7 nitride at the bottom of fins 30 (i.e. on the top of BOX 20). The nitride
8 spacers 65 are used as a mask to structure composite oxide spacers on both
9 sides of the gate 40, formed from oxide layers 50, 32 and 34 (Figure 8C). If
10 the lithography step producing aperture 72 in Figure 8 was processed
11 earlier, the same oxide etch is applied, for a shorter time as less oxide has to
12 be removed.

13 If the lithography step is done earlier, oxide 50 will be still present and the
14 oxide etch is done the same way, just with the mask in place, meaning that
15 only part of the oxide is etched, so that the nitride spacer can be formed in
16 the same way. Outside of aperture 72, the oxide will be as high as the gate
17 after the first oxide etch (Fig. 4.)

18 If different spacer thicknesses for NFETs and PFETs are required, the oxide
19 spacers (50, 32, 34) can be trimmed to (50', 32', 34') using isotropic, wet,
20 vapor or plasma etch processes after masking the areas where thicker
21 spacers are desired, Figure 9. The masking can be done using photo resist. If
22 the optional nitride liner 37 described in Figure 3 was used it is removed at
23 this point using a wet etch process, e.g. hot phosphoric acid. In addition, the

oxide (gate ox/gate reox) has to be removed before the epitaxial step.

Figure 10A shows the result of the selective epitaxial growth step to thicken the fins 30 in the S/D area, thereby lowering the series resistance during operation. The epitaxial step was performed while the gates are encapsulated by the composite spacers, so that the thickness of fins 30 in Figure 10B (which is the thickness of the FinFET body) does not increase. If different thicknesses of the gate spacer are required for NFETs and PFETs, different spacers thicknesses have to be created before the epitaxial step. The thickness of the gate spacers is set such that they cover areas of the fin that contain the conventional halo and extension implants, well known to those skilled in the art, thereby preventing interference with those implants during the doping and subsequent annealing of the S/D.

At this point the process can be continued according to the SARC2 process known to those skilled in the art. This process can also be applied to a process flow in which the source/drain areas are lithographically defined before the silicon fin etch, as described by Choi et al., IEDM 201, p. 421-424.

In summary, the outline of the preferred process flow is:

Form fins to a width that will be the body of the transistor.

form a poly gate intersecting the fins in the transistor body.

- 1 Cover the fins with oxide.
- 2 Form a conformal cap over the projecting gate material (above the oxide
- 3 covering the fins).
- 4 Etch oxide down to BOX, thereby forming a gate cover, and overetch until
- 5 silicon in S/D area of fins is exposed.
- 6 Thicken the fins while the gate is covered by the gate cover.
- 7 In more detail, the process flow is:
- 8 Form fins to a width that will be the body of the transistor.
- 9 Form a poly gate 40 intersecting the fins in the transistor body.
- 10 Deposit, planarize and pre-dope gate poly, deposit oxide 42, nitride cap 45,
- 11 oxide cap 46; define hardmask area (optional resist trim, nitride trim); etch
- 12 gate stack, remove oxide 46
- 13 Oxidize gate, deposit oxide liner; halo and extension implants; nitride liner
- 14 37
- 15 Cover the fins with filler oxide 50, planarize to gate cap.
- 16 Recess oxide 50 to a level above fins and below gate cap.

- 1 Form a conformal cap over the projecting gate material (above the oxide
2 covering the fins).
- 3 Anisotropic cap etch, forming gate sidewalls down to filler oxide.
- 4 Oxide deposition and planarization to improve lithographic process
5 window, if lithographic process window is big enough then these steps are
6 not necessary either
- 7 Lithography, opening window over fins, gate.
- 8 Etch filler oxide down to BOX, thereby forming a gate cover (nitride on top,
9 oxide on bottom), and overetch until silicon in S/D area of fins is exposed.
- 10 Thicken the fins while the gate is covered by the gate cover.
- 11 An alternative process flow that has the advantage of saving one oxide
12 deposition and one oxide planarization step and the disadvantage of leaving
13 some oxide fins that generate topography but can be planarized with a
14 standard (not additional) oxide planarization step later in the process is:
- 15 Form fins to a width that will be the body of the transistor.
- 16 Form a poly gate 40 intersecting the fins in the transistor body.
17 Deposit, planarize, pre-dope poly, deposit oxide 42, nitride cap 45, oxide

1 cap 46; define hardmask area (optional resist trim, nitride trim); etch gate
2 stack, remove oxide 46

3 Oxidize gate, deposit oxide liner; halo and extension implants; nitride liner
4 37

5 Cover the fins with filler oxide 50, planarize to gate cap.

6 Lithography, opening window over fins, gate.

7 Recess oxide 50 to a level above fins and below gate cap)

8 Form a conformal cap over the gates and fins.

9 Anisotropic cap etch, as in previous process sequence
10 Oxide etch down to BOX or, if used, nitride liner

11 Thicken the fins while the gate is covered by the gate cover.

12 Each of the described processes then continues with a standard FinFET
13 process such as that described in J. Kedzierski et al., IEEE Transactions on
14 Electron Devices v.50 n.4 April 2003 p.952-958, or any other convenient
15 method of performing standard back end processing, well known to the art.

While the invention has been described in terms of a single preferred embodiment, those skilled in the art will recognize that the invention can be practiced in various versions within the spirit and scope of the following claims.